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The Open University of Sri Lanka
Department of Electrical and Computer Engineering
ECX6333 – Microwave Engineering and Applications
Final Examination 2011/2012

Time: 0930 - 1230 hrs. Date: 2012- 03 - 08

Answer any FIVE questions.

1.

(a) Vector $\vec{A}$ is given by $\vec{A}=\vec{i}A_x+\vec{j}A_y+\vec{k}A_z$, where $\vec{i}$, $\vec{j}$ and $\vec{k}$ are unit vectors in x-, y- and z- directions respectively.
Show that $\vec{A}$ satisfies the equation $\nabla\times(\nabla\times\vec{A})=\nabla(\nabla.\vec{A})-\nabla^2\vec{A}$

(b) Write Maxwell's equations for free space.

(i) Show that $\nabla^2\underline{E}=\mu\left(\sigma\dfrac{\partial\underline{E}}{\partial t}+\varepsilon\dfrac{\partial^2\underline{E}}{\partial t^2}\right)$

(ii) If the equation given in (i) represents a plane wave propagating in the z-direction, derive an expression for velocity of propagation of the wave.

(c) (i) Show that the charge density ρ caused by the propagation of an electro magnetic wave in a dielectric medium decays according to the equation decays according to the equation $\rho(t)=\rho_0 e^{-\left(\frac{\sigma}{\varepsilon}\right)t}$.

(ii) Find how fast would the current density decay to zero for an e.m.wave of 3 GHz traveling in a copper medium (compare the decay time with the period of the wave). $\sigma=5.96\times10^7\,S/m$ for copper.

2.

Field components inside a rectangular waveguide are given below:

$$\vec{E}_x=j\omega\mu\left(\frac{n\pi}{b}\right)\vec{A}\cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)e^{-j\beta z}$$

$$\vec{E}_y=-j\omega\mu\left(\frac{m\pi}{a}\right)\vec{A}\sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)e^{-j\beta z}$$

$$\vec{H}_x=-j\beta\left(\frac{m\pi}{a}\right)\vec{A}\sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)e^{-j\beta z}$$

$$\vec{H}_y=j\beta\left(\frac{n\pi}{b}\right)\vec{A}\cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)e^{-j\beta z}$$

$$\vec{H}_z = \beta_c^z \left(\frac{n\pi}{b}\right)\vec{A}\cos\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)e^{-j\beta z}$$

$$\vec{E}_z = 0$$

where. $\beta_c^z = k_{c,mn} = \sqrt{\left(\frac{m\pi x}{a}\right)^2 + \left(\frac{n\pi y}{b}\right)^2}$, $\vec{A}$ - constant

(a) What is the mode of propagation in the waveguide?

Now assume that the dominant mode is excited in the waveguide. Waveguide dimensions are $a = 8$ cm and $b = 4$ cm.

(b) Simplify the field components given above at $z = 0$.

(c) (i) Sketch the distribution of E- field across a cross-section of the waveguide.
(ii) Sketch the longitudinal variation of the E-field (y-z plane).

(d) Assuming that the waveguide is filled with air,
(i) find the cutoff wave length of waveguide.
(ii) find the cutoff frequency.

[propagation constant $\gamma_{mn} = j\sqrt{(\beta^2 - \beta_c^{z\,2})}$]

(e) With the help of a diagram explain how the above mode is exited through magnetic coupling.

3.

(a) Portion of a wave guide is to be used in the construction of a cutoff attenuator for a coaxial line. The attenuated signal is then coupled to a horn antenna through a short tapered waveguide in a laboratory setup. Signal frequency is 1 GHz. Dimensions of the waveguide are
a = 10 cm and b = 5 cm.
(i) With the help of a diagram explain how this is done.
(ii) If the required attenuation is 6 dB, find the length of the waveguide.

(b) (i) Why is a tapered rectangular to circular waveguide transition used in a precision variable rotary attenuator?

(ii) With the help of a diagram explain the principle of operation of a variable rotary attenuator.

(iii) The amplitude of the E- field entering the attenuator is E. If the angle of rotation of the resistive pad is θ, find the input and output powers of the attenuator.
(iv) If the required attenuation is 3 dB, calculate the angle of rotation θ.

(c) Why is variable rotary attenuator not suitable for high power applications?

4.

(a) A cylindrical waveguide is filled with air. The waveguide is excited using a Wave meter with variable frequency. As the frequency of the wave meter is increased, find the frequency at which TM_{12} just begins to propagate.

The waveguide has a diameter of 10 cm.
Cutoff properties of a cylindrical waveguide is given by $J_n(k_c a) = 0$

(b) A cylindrical resonator is filled with a dielectric material having $\varepsilon_r = 3$ and $\mu_r = 1$. Inner diameter of the resonator is 10 cm. If the resonator resonates in TM_{231} mode find the frequency of the resonator. The length of the resonator is 10 cm. The resonator wave length $\lambda_r = \dfrac{2\pi}{\sqrt{k_c^2 + \left(\dfrac{l\pi}{d}\right)^2}}$

(c) What is the relationship between the middle length of the waveguide loop (L_{mid}), resonance wave length (λ_r) and the guide wave length λ_g of a traveling wave resonator?
A traveling wave resonator operating in the dominant TE mode has a breath $a = 4$ cm. The middle length of the waveguide loop is 10 cm. If the guide wavelength is 5 cm, find the frequency of the resonator.

(d) Briefly explain the principle of operation of

(i) Two cavity Klystron
(ii) Traveling Wave Tube (TWT)

5.

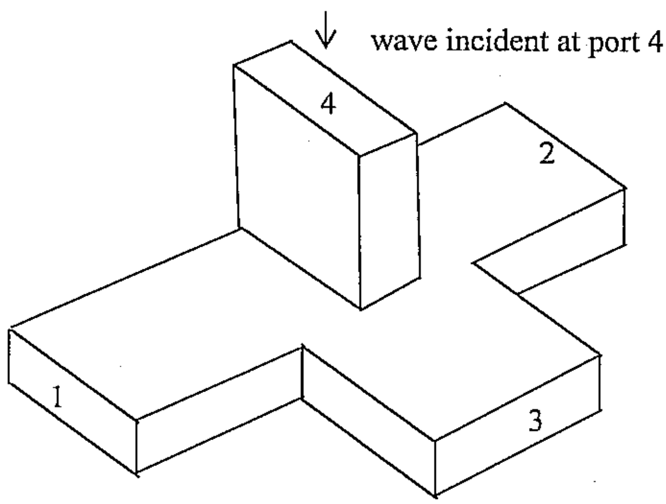

Fig.1 Magic Tee

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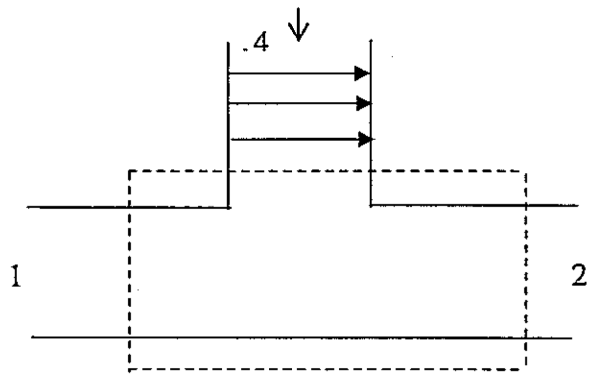


Cross-sectional view

A Magic Tee and it's cross-sectional view is shown in Fig.1
A wave is entering at port 4 and it's E-field distribution at the entrance of port 4 is given in the diagram.

(a) Sketch the E-field distribution in port1, port2 and complete the E-field distribution for port 4. (Sketch the E-field distribution inside the dotted rectangle.)
(b) What is the phase difference between the field components in port 1 and port 2?
(c) What is the relationship between the s-parameters s_{14} and s_{24}? Justify your answer.
(d) What can you say about the coupling between port 4 and port 3? Deduce value of s_{34}.
(e) What are the s-parameters that are equal to each other? Justify your answer.
(f) Write the s-matrix using minimum no. of parameters.
(g) If the junction is lossless write necessary equations for the device using (f).
(h) If ports 3 and 4 are matched, find the missing s - parameters and write the final s -matrix for the Magic Tee.
(i) Find the voltage standing wave ratio (VSWR) at port 1?

6.
(a) Show that if all ports of a reciprocal and a lossless four port junction is matched it is a directional coupler.

(b) With the help of two directional couplers, show how the forward – and reflected power measurement can be taken simultaneously using a ratio meter. Your answer must include a clearly labeled diagram.

(c) (i) What is the distance s between the two holes in *a two-hole coupler*?
(ii) Briefly explain why above value is chosen for s.
(iii) What would happen if $s = \frac{5\lambda_g}{2}$ for *a two-hole coupler*?

7.
(a) Briefly and clearly explain the following terms in relation to cellular radio systems. Use diagrams whenever necessary.

(i) Sectoring
(ii) Frequency reuse
(iii) Handoff

(b) A certain area is covered by a cellular radio system with 84 cells and a cluster size *N*. Number of voice channels available for the system is 300. Users are uniformly distributed over the area covered by the cellular system. The offered traffic per user is 0.05 *Erlang*. Assume that blocked calls are cleared and the designated blocking probability is $P_b = 1\%$.

(i) Determine the maximum carried traffic per cell if cluster size $N = 4$ is used.
(ii) Repeat (i) for cluster size $N = 12$.
(iii) Determine the maximum number of users that can be served by the system for a blocking probability of 1 % and cluster size $N = 12$.

(c) (i) What is fading? How does fading affect a radio communication network?
(ii) Define the terms *level crossing rate* (LCR) and *average fade duration.*
(iii) LCR for Rayleigh fading is given by the equation $N_R = \sqrt{2\pi} f_m \rho \, e^{-\rho^2}$.
What is f_m? What is ρ?

8.
(a) Describe the principle of a geostationary satellite?
(b) What is the function of a satellite transponder? How is satellite transponder powered?
(c) Why do the satellite uplink- and down frequencies differ?
(d) In a satellite earth station it is necessary to track the satellite for its slight variations of position. Antenna thus adjusts its azimuth- and elevation angles constantly for efficient operation of the system.
What technique is used for antenna tracking?

(e) Explain the operation of the following subsystems:

(i) Satellite communication uplink
(ii) Satellite communication downlink

Table1 Capacity of an Erlang B System

Number of Channels C	Capacity (Erlangs) for GOS = 0.01	= 0.005	= 0.002	= 0.001
2	0.153	0.105	0.065	0.046
4	0.869	0.701	0.535	0.439
5	1.36	1.13	0.900	0.762
10	4.46	3.96	3.43	3.09
20	12.0	11.1	10.1	9.41
24	15.3	14.2	13.0	12.2
40	29.0	27.3	25.7	24.5
70	56.1	53.7	51.0	49.2
100	84.1	80.9	77.4	75.2

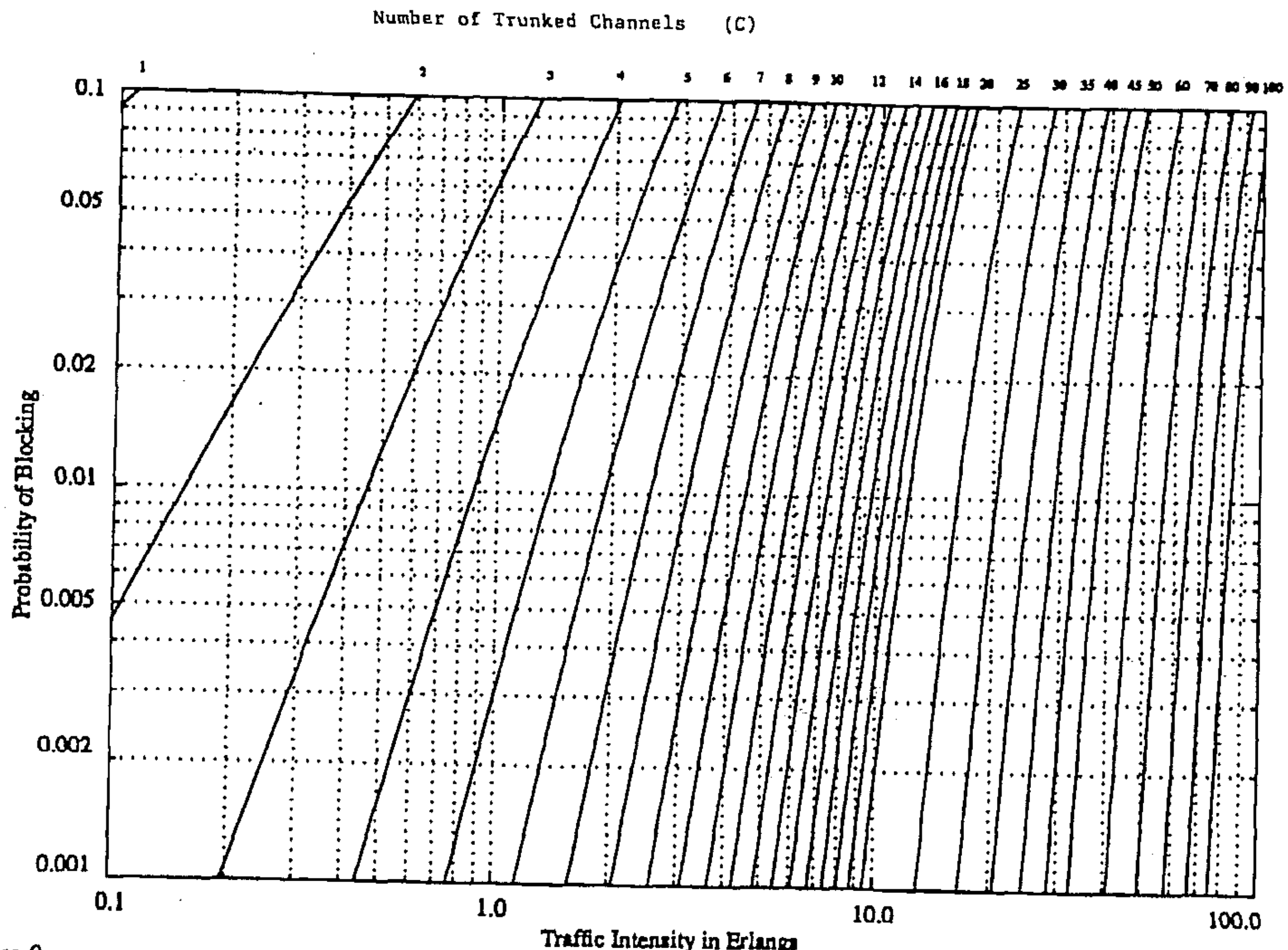
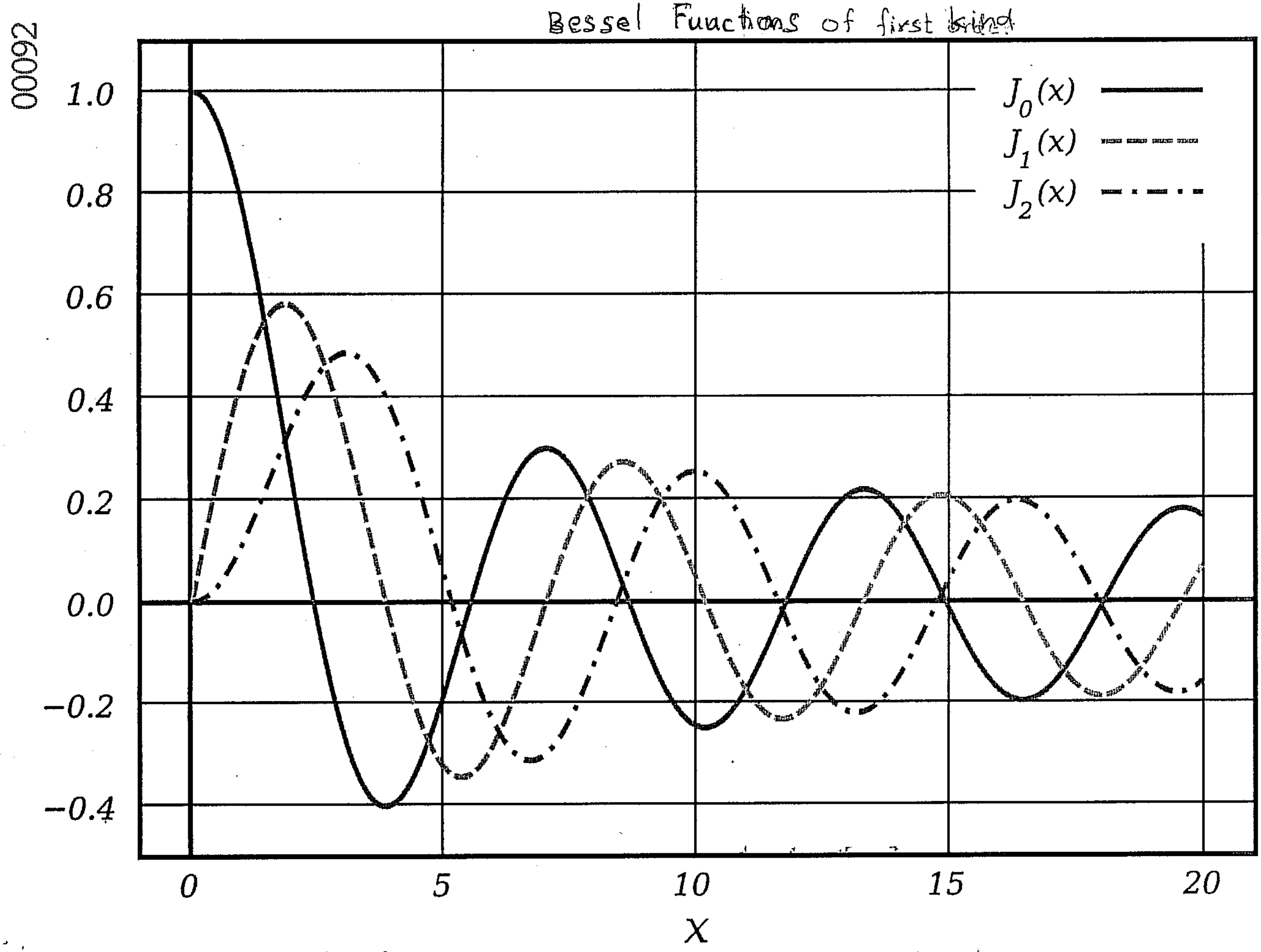


Figure 2.
The Erlang B chart showing the probability of blocking as functions of the number of channels and traffic intensity in Erlangs.


Bessel Functions of first kind
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1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
J0(x)
J1(x)
J2(x)
0
5
10
15
20
X